Applied Science and Innovative Research
ISSN 2474-4972 (Print) ISSN 2474-4980 (Online)
Vol. 7, No. 2, 2023
www.scholink.org/ojs/index.php/asir

Original Paper

Application of Grouting Water Plugging Technology in Enriched Water Mountain Tunnel

Dong Tianxiong[1], Deng Yuewen[1] & Qi Gaoyuan[2]

[1] China Merchants Chongqing Highway Engineering Testing Center Co., Ltd., Chongqing, 400067, China

[2] China Municipal Engineering Central South Design & Research Institute Co., Ltd., Wuhan, 430064, China

Received: May 8, 2023 Accepted: May 23, 2023 Online Published: May 26, 2023

doi:10.22158/asir.v7n2p148 URL: http://doi.org/10.22158/asir.v7n2p148

Abstract

In the expressway built in Chongqing northeast region, the tunnel occupies a large proportion in the total mileage. Long mountain tunnels with large buried depth and complex geological conditions are common in this area, which are prone to water gusher disasters during construction, which seriously threaten the construction quality and affect the operation of the expressway after it is completed and opened to traffic. In this paper, Jixinling Tunnel under construction in Wuzhen Expressway is taken as an example. Combined with advanced geological forecast data and site conditions, appropriate grouting materials and reasonable and feasible construction technology are selected for the surrounding advanced curtain grouting reinforcement and water plugging treatment, which effectively controls the water gushing disaster of the tunnel and ensures the safety of the construction process. It can provide some reference for the treatment of water gushing disease in mountain tunnel under similar geological conditions.

Keywords

Mountain tunnel, gushing water, grouting water plugging, grouting material

1. Introduction

In Chongqing, the coverage of mountain area is more than 70% of the total land and the surface fluctuation is quite obvious, especially in the middle reaches of Yangtze River, the northeast region in Chongqing. The presence of mountains like Daba Mountain, Wu Mountain merely takes the place of plains, which results to the frequent construction of long mountain tunnels with large buried depth and complex geological conditions among the expressways built in Chongqing northeast region. Tunnels in

this region often suffered from geological disasters like weak fracture zone, water gushing and increased faults, especially the water gushing problem during the process of construction due to the growth of rock structure of fracture zone, the low stability and strength of wall rock, as well as the stress strain phenomena like fracture, rising and extruding within the rock-soil mass and its spacial anisotropy. If not properly handled, these problems will not only affect the construction safety but also trigger serious disease after the construction of the tunnel.

The water gushing problem in tunnel face and wall rock generally can be solved by grouting water plugging which refers to plugging grouting material into weak stratum and hole by grouting equipment under certain pressure in order to achieve reinforcement, leak-proof, padding, rectification, rising etc. (Cheng, n.d.; Pengfei, 2019; He, Lai, Wang, et al., 2020). This paper investigates the grouting water plugging technology in resolving the gushing disaster of mountain tunnel by taking the construction of Jixinling Tunnel in Wuzhen Expressway in northeast Chongqing region.

2. Background of the Project

2.1 Basic Information of the Tunnel

Jixinling Tunnel in Expressway of Wuzhen in Chongqing to Zhenping in Shannxi, extends from Chayuanzi Village, Xujia Town, Wuxi County, Chongqing to Sanping Village, Zhenping County, Shannxi Province. The starting milage of the left hole is from ZK42+545 to ZK48+726, extending 6181 meters; the starting hole of the right hole is from ZK42+570 to ZK48+720, extending 6150 meters. The grouting water plugging discussed in this paper aims to resolve the water gushing and mud bursting disease of left hole in the part from ZK46+121 to ZK46+146.

2.2 Basic Information of Geological Condition

The rank of wall rock in Jixinling Tunnel left hole from ZK46+121 to ZK46+146 is level IV, and the combination among layers is in average condition. The wall rock of the excavation tunnel face is gray limestone with shale locally, which is mainly in thin-layer massive structure. The rock mass is relatively soft with developed joints, slightly opened and partially closed cracks. Most part of the tunnel face is dry and partially wet.

2.3 General Situation of Construction Site

The water inflow in the left hole of Jixinling Tunnel changes with the rainfall intensity, which increases significantly after continuous rainfall and has pressure bearing property. On September 16, 2022, a mud burst and water gushing occurred at ZK46+147 part of the left hole, with a water volume of about 1440m^3 and an water yield of about 180m^3 per hour. By September 20, 2022, large water inflow has occurred repeatedly for 4 times, with the maximum water yield of about 180m^3/h, each lasting for 4~6h, and the accumulated sediment of about 30000m^3. According to the three-month monitoring data of part from ZK46+121 to ZK46+146 water gushing section, the maximum water gushing volume per day is 20000m^3. The water gushing point was jet-like when just exposed, and the maximum jet distance was 12m~20m, with a maximum water pressure of 0.80MPa. In order to ensure the construction safety and

improve the grouting water plugging effect, it is necessary to reasonably select the grouting materials and design the construction technology according to the actual situation in combination with the stratum characteristics of zk46+121 to zk46+146 section of the left hole of Jixinling Tunnel. See Figure 1 for the water gushing condition at the site of the left hole of Jixinling tunnel.

Figure 1. Water Gushing Condition at Site

3. Grouting Material for Water Plugging

Grouting water plugging can plug fracture thus to keep the integrity of wall rock, block the water tunnel and strengthen the broken rocks. The material will displace the water and air in the fracture of rock, improve the original properties of soil and rock, reduce the water permeability in rock and soil, and improve the compressive resistance, shear strength and impermeability of soil (Hongan & Yan, 2014; Jie, n.d.; Mijia, Mingxiong, & Yongnian, 2001). The grouting material directly affects the treatment effect, and some attentions paid to selection are as follows:

(1) The slurry for grouting water plugging must be sticky, and the concretion formed by the slurry after construction should be solid enough;

(2) The slurry used shall have good fluidity and permeability, and can reach the expected gap or cavity during construction while enlarge the scope of action after the grouting;

(3) The slurry shall have certain stability to prevent excessive precipitation from affecting the grouting effect during the pressure grouting process;

(4) When the fault fracture zone and sandy gravel stratum with crack width B > 1mm or permeability coefficient $K \geq 5 \times$ In 10^{-4}m/s, double slurry of cement-sodium silicate or single cement slurry mixed with admixtures should be selected;

(5) When the fault fracture zone with crack width B < 1mm or permeability coefficient $K \geq 1 \times$ In 10^{-4}m/s, sodium silicate, which is a kind of soluble inorganic silicate (Huijuan & Youxin, 2014), whose modulus determines the solubility in water because the greater the modulus, the more difficult it is to dissolve in water (Jingyun, 2015), and the higher the stone strength, should be select. In tunnel construction, sodium silicate with modulus between 2.0 and 3.5 is generally used as material.

(6) In case of large surrounding rock fissures, mud and water inrush and other conditions in the karst section of the tunnel, the splitting method can be used if the site conditions permit.

(7) If the single cement slurry or double slurry of cement-sodium silicate can not achieve the effect of grouting and water plugging in the rock stratum with fine cracks or in the case of difficult grouting and large water gushing, the chemical slurry can be used for construction. Common chemical grout include polyurethane grout, acrylic grout and chrome lignin grout (China RAILWAY NO.2 Engineering Group Co., Ltd., 1999), in which polyurethane grouting material is most used in tunnel grouting and water plugging construction.

According to the site water gushing condition of Jixinling Tunnel, the single slurry of quick hardening sulphoaluminate cement is used in the normal curtain grouting within the general grouting range. In case of excessive water gushing, the polyurethane slurry is used for construction, and the cement sodium silicate double slurry is immediately used for plugging in case of slurry leakage. The single slurry of quick hardening sulphoaluminate cement is mixture of cement as raw material with water, and admixtures are added to adjust the process performance when necessary. Due to the different types of cement and admixtures, various types of cement slurry can be formed to meet the needs of plugging under different hole depths and temperatures (Fenglin, 2009). It mainly has the following characteristics: good impermeability after concretion, high strength and stability, and small decrease in strength; Good fluidity and irrigability; adjustable proportion of cement slurry according to actual needs. The double slurry of cement and sodium silicate is a kind of cement that reacts after mixing with water to generate hydrated $CaSiO_3$ gel. The later sodium silicate and additives can accelerate the reaction of Ca^{2+}in the cement slurry to continue to generate hydrated $CaSiO_3$ gel. The more gels generated, the less fluidity of the slurry, and finally solidify into a relatively stable concretion. The early strength of the concretion is provided by the reaction between sodium silicate and $Ca(OH)_2$ in the slurry, while the later strength depends on the gradual deepening of cement hydration reaction. The main features of cement water glass double slurry water shutoff are as follows: the slurry has a wide source of raw materials and low cost; the gel time is easier to control than that of single liquid cement slurry, which can effectively control the grouting range; it is easy to form concretion under dynamic water conditions; the strength of the concretion of the slurry is high, and the early strength increases rapidly; the concretion rate is high, up to 100%; the slurry has good permeability. Polyurethane grouting material has obvious effect in the case of large water inflow in the tunnel. It foams in the presence of water and thus has the dual functions of elastic water stop and expansion water stop. It has been applied for many times in the grouting and water plugging of dynamic water strata (Zhu, Ren, Jun, & Zhili, 2020; Hongli, Huilu, et al., 2016; Daochuan, 2018). The strength of cement slurry generally takes the compressive strength as the main evaluation index (Mijia, Mingxiong, & Yongnian, 2001), and the gel time is related to the slurry water cement ratio. The mix proportion and performance index of grouting water shutoff slurry shall meet the requirements shown in Table 1 and Table 2 below.

Table 1. Slurry Ratio Parameter

No.	Name	Ratio parameter	
		Water-cement ratio	Cement-sodium silicate volume ratio
1	Single slurry of quick hardening sulphoaluminate cement	W:C=(0.6~1):1	/
2	Double slurry of cement and sodium silicate	W:C=(0.8~1):1	V_c:V_s=1:1

Table 2. Performance Index of Sulphoaluminate Cement Single Slurry

Water-cement ratio	Gel time	Compressive strength/MPa				
		8h	12h	3h	7h	28h
0.6:1	24min	8.8	20.8	22.6	27.8	28.9
0.8:1	1h20min	6.2	17.1	18.8	21.0	22.4
1:1	1h35min	5.3	13.8	15.5	18.6	19.7

4. Grouting Water Plugging Technology

In order to ensure the safety of the construction site in the process of tunnel excavation and the smooth passage through the water gushing section, before construction, TGP and other instruments are used to detect the adverse geological conditions within 60m in front of the tunnel head, to master its attributes, more accurate location and spatial distribution scale, and then the surrounding advanced curtain grouting reinforcement and water plugging technology is used for design and construction. According to the water gushing situation and geological conditions of Jixinling Tunnel, the range of grouting water blocking and the number of grouting holes are determined, and the appropriate grouting machines and tools are selected. After the grout stop wall and drilling rig operation platform are set up, the installation and drilling of the orifice pipe are carried out, and then the grouting is carried out according to the construction machinery and site conditions, and finally the grouting situation is checked to see whether it achieves the expected effect. Through the surrounding advanced curtain grouting reinforcement and water plugging technology, a concretion with certain strength and stability is formed outside the excavation contour, so as to improve the bearing capacity of surrounding rock and ensure the excavation safety. In order to achieve better grouting effect, the specific parameters of grouting process can be adjusted by field test in the tunnel water gushing section.

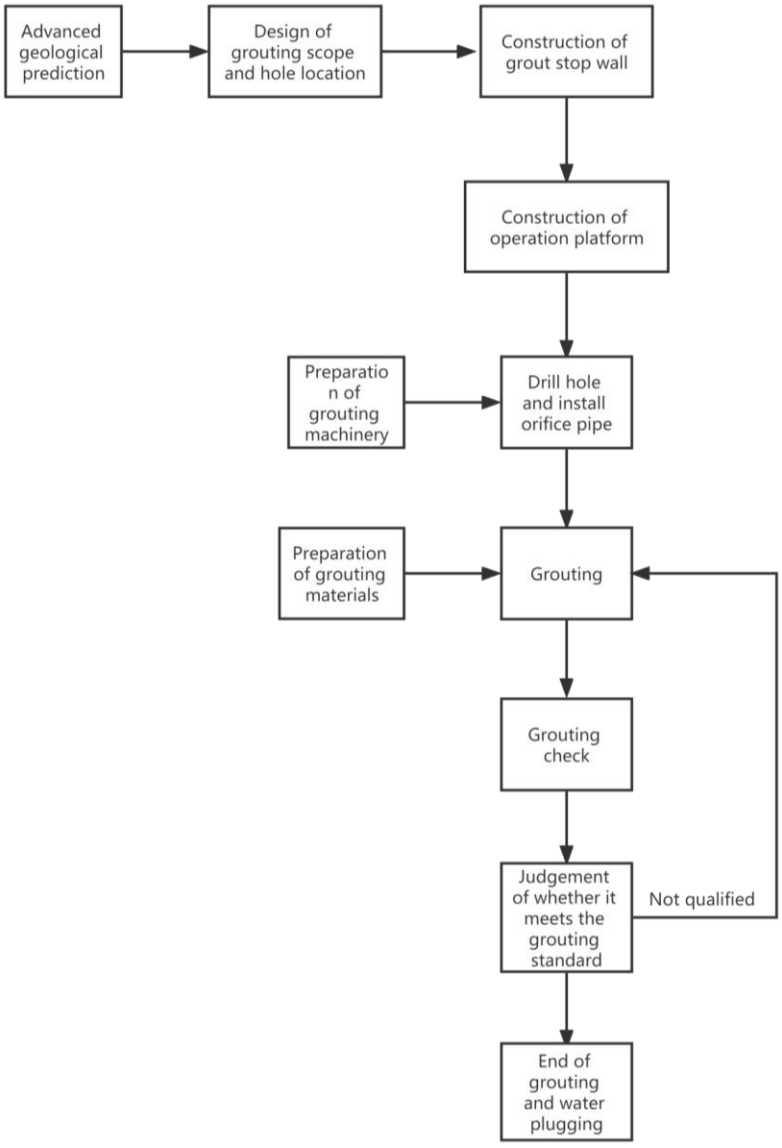

Figure 2. The Process of Grouting Technology

(1) The scope of grouting water plugging

8~10m outside the tunnel excavation contour line is allowed.

(2) Grouting machine

The multi-functional fast integrated drilling rig is selected for the grouting water plugging construction. The drilling rig has the functions of water and grout stop, and has various level of pressure orifice water stop devices. Equipped with automatic grouting recorder to timely collect data and upload it to the network computer, the drilling speed can reach above 10-20m per hour.

(3) Construction of grouting wall

Whether the grouting wall is reasonably set directly affects the effect of grouting water plugging. It must be able to withstand the maximum grouting pressure and prevent slurry leakage. The grouting wall is set with a thickness of 3m. C30 concrete is used for pouring in steps. Two layers of

reinforcement mesh with a diameter of 2mm and a grid spacing of 30cm are implanted before pouring, and then C30 concrete is used for pouring in steps with the height of 1.5~2.0m each step. The grouting wall and the excavation contour line are connected with 22mm diameter threaded reinforcement at a circular spacing of 50cm. The two ends of the reinforcement are embedded in the grouting wall and the surrounding rock for 50cm respectively. The concrete shall be vibrated and compacted during pouring. Before the construction of the first circulation grouting wall, the top water grouting shall be carried out for the exploratory hole first, so that there is basically no water leakage at the tunnel face or the headrace hole is embedded at the bottom of the grout stop wall. The orifice is provided with a gate valve, and the headrace orifice pipe is connected to the outside of the grout stop wall.

(4) Hardening of working platform

After the construction of grouting wall is completed, a drilling rig working platform is set behind it to meet the needs of site construction and ensure the construction progress of grouting water plugging. The platform is about 10m away from the grouting wall and is about 10m long. The top is flush with the tunnel arch line. After the top soil layer is compacted, C20 concrete is used to harden the surface.

(5) Installation of orifice pipe

A drill is required to drill holes to install orifice pipes before drilling. The drill bit diameter is 130mm. After drilling to a depth of 4.8m, an orifice pipe with a diameter of 108mm and a length of 5m is installed. After the installation of the orifice pipe, the geotextile with a length of about 60cm is used to wind on its outer wall, and finally the drill is used to drill to the required depth. The cement slurry mixed with waterproof agent shall be used for consolidation between the orifice pipe and the wall rock to prevent slurry leakage during the grouting process, which will adversely affect the grouting effect.

(6) Drilling

Mark the tunnel cracks before drilling, so that the crack position can be accurately found during drilling and subsequent grouting construction. A high-pressure gate valve is installed outside the orifice pipe. A grouting hole with a diameter of 90mm is drilled through the orifice pipe and drilled through the grout stop wall to a depth of 5~10m.

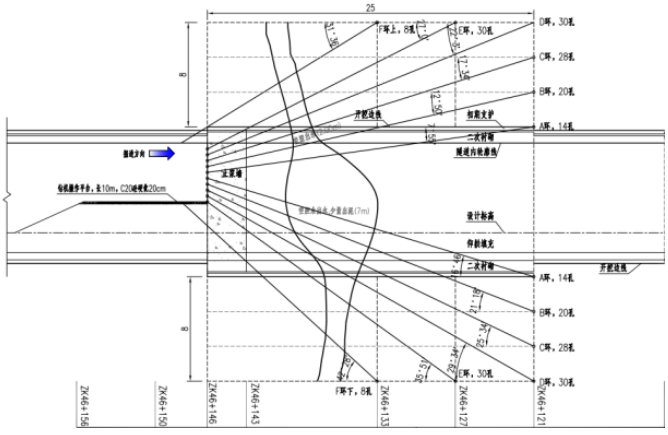

Figure 3. Layout of Hole Location

(7) Grouting

The grouting adopts the method of forward sectional grouting combined with hole bottom grouting. If there is no water gushing in the borehole, grouting can be carried out at one time; If there is water gushing in the borehole, stop grouting and use the forward grouting method instead. The section length is determined according to the water volume in the borehole: when the water volume in the borehole is 0~10m^3/h, the section grouting length is 10m; when the water volume in the hole is 10~30m^3/h, the sectional grouting length is 5m; if the water volume in the hole is greater than 30m^3/h, the grouting shall be stopped immediately. If it is difficult to inject grout due to excessive water pressure, PVC pipes can be installed in the hole for hole bottom grouting. When necessary, multiple grouting machines can be used to carry out grouting construction, so as to effectively reduce the time consumption of grouting and make the construction efficiency higher (Ping, 2017).

(8) Inspection of grouting effect

After grouting, observe whether there is wireless water on the surface. After the grouting of a section, the grouting effect is checked by drilling inspection holes. The drilling position of inspection holes can be selected in the weak grouting area (Xingtao, 2014), and the number of inspection holes is 5% of the total number of boreholes. The slurry in the inspection hole shall be fully filled without flowing water and mud gushing; The single water yield in the inspection hole shall be less than 0.2L/min, and the total water yield shall be less than 30L/min; The core shall be taken according to 70% of the number of inspection holes. The 7-day compressive strength of the stone body shall be greater than 5MPa, the integrity rod index shall reach 75~80, and the permeability coefficient shall be less than 10-5cm/s. If the expected effect is not achieved, the number and density of grouting holes must be increased for grouting again.

Seven days after the completion of grouting, the drilling verification is carried out, and the number of boreholes is 7. There is no flowing water and mud gushing in the hole; the number of cores is 5, and the compressive strength is 5.3mpa, 6.2mpa, 5.6mpa, 7.0Mpa and 6.7mpa respectively; the rod indexes of core samples were 93, 91, 86, 86 and 90, which all meet the requirements.

5. Conclusion

Aiming to solve the water gushing problem in Enriched water mountain Tunne， based on the case of Jixinling Tunnel in Wuzhen Expressway, this paper analyzes the geological conditions and site construction conditions of the water gushing section from zk46+121 to zk46+146 in the left hole of the tunnel. The surrounding advanced curtain grouting reinforcement and water plugging technology is used to replace the conventional construction measures, which ensures the construction safety of the tunnel when passing through the water rich fault fracture zone, and effectively controls the water gushing in the tunnel. It also provides a certain reference for the grouting water plugging construction of mountain tunnel with similar condition. The detailed conclusions are as follows:

(1) The water gushing disaster during the excavation of this tunnel has large water pressure and flow, which endangers the safety of on-site construction. Therefore, in the construction of Enriched water mountain Tunnel, attention should be paid to the advanced geological prediction, and reasonably use TGP, transient electromagnetic method and other technologies to ensure the construction safety.

(2) The selection of grouting slurry, the mixture ratio of slurry and the grouting method are all key to the grouting effect. Tunnels with different geological conditions have different parameters. Therefore, in the design of construction technology, it is necessary to integrate the advanced geological prediction data and field tests, and adjust the grouting parameters dynamically.

References

Cheng, L. (n.d.). *Study on Properties and Application of Novel Grouting Materials and Rock Reinforcement Mechanism for Water-Rich Faulted Fracture Zone*. Guangzhou: Guangzhou University.

China RAILWAY NO.2 Engineering Group Co., Ltd. (1999). *Tunnel* (pp. 261-268). Beijing: China Railway Publishing House Co., LTD.

Daochuan, Q. (2018). Research Summary of Oil Soluble Polyurethane Grouting Material. *China Building Waterproofing*, *2018*(17), 1-5.

Fenglin, T. (2009). *Core Drilling*. Wuhan: China University of Geosciences Press.

He, S., Lai, J., Wang, L., et al. (2020). A literature review on properties and applications of grouts for shield tunnel. *Construction and Building Materials*, *239*, 117782. https://doi.org/10.1016/j.conbuildmat.2019.117782

Hongan, L., & Yan, L. (2014). Reinforcement Technology of Advance Deep-hole Grouting for Shallow Excavation Tunneling in Water Rich Sandy Cobble Stratum. *Journal of Municipal Technology*, *2014*(5), 83-86.

Hongli, W., Huilu, L., et al. (2016). Preparation of One-component Water-soluble Polyurethane Plugging Grouting Material. *China Adhesives*, *25*(9), 25-28.

Huijuan, Zh, & Youxin, Zh. (2014). Discussion on Production Process of Sodium Silicate. *Glass*, *41*(02), 12-16.

Jie, Zh. (n.d.). *Study on the Grouting Mechanism and Construction Techniques in Freeze-sealing Pipe Roof*. Suzhou: Soochow University.

Jingyun, Y. (2015). Analysis on Development and Prospect of Sodium Silicate. *China Cleaning Industry*, *2015*(08), 39-42.

Mijia, Y., Mingxiong, Ch, & Yongnian H. (2001). Stimulating Experiment for Grouting Seepage in Rockmass. *Journal of Experimental Mechanics*, *3*(16-1), 105-112.

Mijia, Y., Mingxiong, Ch, & Yongnian, H. (2001). Current Research State of Grouting Technology and its Development Direction in Future. *Chinese Journal of Rock Mechanics and Engineering*, *2001*(06), 839-841.

Pengfei, Q. (2019). New Development of Grouting Technique Unfavorable Geological Conditions. *Metal Mine*, *2019*(6), 1-5.

Ping, Ouyang. (2017). *A Research on the Tactical Technology to Protect and Emit Limited the Groundwater of ChunTianMen Long Tunnel*. Chongqing: Chongqing Jiaotong University.

Xingtao, F. (2014). Research on Advanced Grouting and Plugging Water at High-pressure Rich Water Section at Zhongtianshan Tunnel. *Shanxi Architecture*, *40*(6), 178-180.

Zhu, Y., Ren, X., Jun, W., & Zhili, W. (2020). Preparation of underwater quick-set and expansion polyurethane Grouting Material and its Properties. *Coal Geology & Exploration*, *2020*(5), 78-80.